Climate Change Will Impact the Seattle Department of Transportation

Photo Source: Seattle Municipal Archives

"Shrinking glaciers on Mt. Rainier are one sign of global warming."

-Seattle City Light Web site

Audit Team: Wendy K. Soo Hoo, Assistant City Auditor
Megumi Sumitani, Assistant City Auditor

City Auditor: Susan Cohen

Office of City Auditor

PO Box 94729
Seattle, WA 98104-4729

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City of Seattle
Office of City Auditor
Susan Cohen, City Auditor

August 9, 2005

The Honorable Greg Nickels
Seattle City Councilmembers
City of Seattle
Seattle, Washington 98104

Dear Mayor Nickels and City Councilmembers:

Attached is our study of the potential impacts of climate change on the Seattle Department of Transportation. Government leaders around the world have acknowledged that climate change is an increasingly urgent issue. Climate change is likely to have a significant financial impact on the City of Seattle and affect a wide range of functions, including electricity generation, water availability, and street conditions. We conducted this review of the Seattle Department of Transportation to explore how changes in the region's climate could affect the department's functions, services, and infrastructure. The Seattle Department of Transportation and University of Washington Climate Impacts Group reviewed this report and their official responses can be found in Appendices 5 and 6.

We would like to acknowledge the assistance and professionalism of all City personnel who participated in this review, including managers and staff from the Seattle Department of Transportation, Seattle Public Utilities, and the Office of Sustainability and Environment. We also sincerely appreciate the technical feedback and assistance provided by scientists at the Climate Impacts Group. If you have any questions, please call me at (206) 233-1093.

Sincerely,

Susan Cohen

Susan Cohen
City Auditor

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Introduction

Scientists have reached a broad consensus that climate change is occurring, that its effects will be dramatic, and that it will pose significant challenges for policymakers.[1] Government leaders around the world have acknowledged that climate change is an increasingly urgent issue. In fact, the importance of climate change was underscored when it was identified as a critical global issue at the 2005 G8 (Group of Eight Industrialized Nations) Summit in Scotland.

Climate change is likely to have a significant financial impact on the City of Seattle and affect a wide range of functions, including electricity generation, water availability, and street conditions. For example, a recent engineering and policy study projected that the Boston metropolitan area will incur costs of $94 billion during the 21st century as a result of climate change-related property damage, higher energy prices, and a greater need for emergency services.[2]

Regarding climate change, policymakers have two challenges to address. First, policymakers need to focus on actions to *prevent* or slow climate change by reducing human-generated pollutants that worsen climate change. The City of Seattle has been a national leader in its efforts to reduce the pollutants that cause climate change. Second, policymakers need to focus on actions to effectively *adapt* to changes in climate.

To assist policymakers in developing adaptive strategies, the Office of City of Auditor has initiated a series of reviews on how changes in the Pacific Northwest region's climate will impact the operations and infrastructure of various City departments. This first review focused on the Seattle Department of Transportation. This study does not provide a comprehensive scientific analysis; its purpose is to raise awareness of and assess the potential impacts on Seattle's transportation operations and infrastructure.

Results in Brief

During interviews with Seattle Department of Transportation (SDOT) managers, we identified five areas that could be impacted by climate change: 1) flooding and landslides; 2) seawall conditions; 3) bridge conditions; 4) roadway conditions; and 5) trees and vegetation in the public rights-of-way (urban forestry). SDOT has begun to consider climate change's potential impacts to urban forestry and the design for the new Alaskan Way Seawall, and recognizes that in the future the department will have to consider additional associated risks. The department has not included climate change as a factor in its overall long-term planning, consistent with the results of a survey we conducted of five other transportation agencies. As the Boston study indicates,

[1]City of Seattle Office of Sustainability and Environment (OSE) Web site.

[2]The CLIMB (Climate's Long-Term Impacts on Metro Boston) Project was conducted over a five-year period by a research team of policy and engineering experts from the University of Maryland and Tufts and Boston Universities. The CLIMB project is the first detailed study of climate change impacts for a metropolitan area in the United States. The Project was commissioned by the U.S. Environmental Protection Agency, to examine integrated impacts and response strategies for the Boston metropolitan area.

local jurisdictions need to thoroughly address climate change as a factor in long-term planning to mitigate impacts to their operations and infrastructure.

Because climate change will likely have significant impacts on the City of Seattle, it would be prudent for SDOT and City officials to begin considering how to effectively address these potential impacts. In particular, the following issues should be considered:

Alaskan Way Seawall Replacement May Not Be High Enough. SDOT plans for the seawall replacement appropriately recognize that sea level will increase during the 21st century. However, sea level projections from a University of Washington climate impacts research group suggest that the City's current design standards for the new seawall may not adequately account for the potential projected rise in sea level. The Seattle Department of Transportation and the Office of City Auditor recognize that multiple scientific projections have been made to estimate the increase in sea level and the rate of the increase over the next century. SDOT and the Office of City Auditor also recognize that scientific expertise is needed to thoroughly evaluate these different calculations and projections. Given the magnitude of the Alaskan Way Seawall project's long-term financial and transportation impacts, we recommend that the City obtain a comprehensive, independent analysis which considers all available scientific sources to estimate the probabilities of the increase and rate of increase in sea level.

Long-Range Interdepartmental Planning Is Needed. SDOT officials indicated that sea level rise is a Citywide concern that affects multiple departments, including Seattle Public Utilities, Seattle City Light, the Department of Parks and Recreation, and the Department of Planning and Development. If these departments develop independent projections of sea level rise, they may use conflicting standards in City policy decisions or capital project designs. SDOT officials, however, indicated that the City could only revise existing standards or establish new standards to reflect changes in climate as long as they remained consistent with funding agencies' requirements.

SDOT officials suggested that an interdepartmental team could coordinate a comprehensive assessment of data on projections for sea level rise, as well as other issues related to climate change. The interdepartmental team would be responsible for identifying which sea level and other climate-related projections all City agencies should utilize in establishing design standards or making policy decisions.

The interdepartmental team would most likely require expert assistance to collect and analyze data as a basis for policy decisions by the Mayor and City Council. Establishing an interdepartmental team would allow departments to share costs associated with scientific research and analysis. Furthermore, because climate change will have impacts beyond the City of Seattle, the interdepartmental forum would benefit from inviting participation from or coordinating efforts with other regional agencies. This would provide a forum to begin considering how to address climate change impacts from a regional perspective.

Background

Recent scientific studies and implementation of the Kyoto Protocol in 141 countries have called attention to global and regional climate change.[3] Studies conducted by local climate experts have described the changes expected to occur in the Pacific Northwest region, including warmer temperatures, increased winter rainfall, reduced summer precipitation, and rising sea levels. As a result of these changes, scientists predict the Pacific Northwest will experience more frequent winter landslides and floods, and summer droughts; deterioration of fish habitat; and a significantly reduced mountain snowpack.

Recent weather occurrences and trends suggest that the region's climate may already be changing. For example:

- The Cascades snowpack, which the region depends on for drinking water, hydroelectricity, recreation, fish habitat, and irrigation, has declined substantially since 1950;
- Seattle has experienced two incidents of 100-year storms in the last eight years; [4]
- Washington and Oregon ski resorts closed in early 2005 because of insufficient snow;
- Washington's governor declared a statewide drought emergency in March 2005, with water levels for many Washington rivers at or near record lows; and
- Warm water temperatures may be responsible for the disappearance of as many as 200,000 sockeye between the Locks and their spawning grounds in streams beyond Lake Washington.

Recent scientific research indicates that climate change will likely have significant impacts on resources, communities, and industries. Because responses to mitigate these impacts are likely to have substantial costs, the Office of City Auditor conducted a review of the Seattle Department of Transportation (SDOT) to explore and provide a high-level overview of how Seattle's transportation system might be affected by a changing climate in the Pacific Northwest.

In Addition to Numerous City Initiatives to Reduce Greenhouse Gas Emissions, A Need Exists to Plan Adaptive Strategies

Reducing the greenhouse gas emissions that contribute to climate change has been a City priority since the early 1990s. (See Appendix 4, City of Seattle Office of Sustainability and Environment's Climate Protection Web Site.) The City of Seattle has implemented numerous initiatives and programs to reduce its greenhouse gas emissions, which scientists believe are exacerbating climate change.

In 2000, the City adopted Resolution 30144, committing the City's municipal-owned electric utility Seattle City Light, to an electric energy resource strategy that produces zero net greenhouse gas emissions. Seattle City Light is now implementing the resource strategy by contracting for programs and projects that mitigate the carbon dioxide emissions associated with City Light power purchases.

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[3]The Kyoto Protocol is an international agreement to address global production of greenhouse gas emissions.
[4]A 100-year storm is a storm of intensity and duration that has a 1 percent (one in 100) chance of occurring in any given year based on statistical modeling.

In 2002, the Office of Sustainability and Environment completed an inventory of greenhouse gas emissions produced by Seattle. The inventory showed that the City reduced greenhouse gas emissions attributable to its own operations by 48 percent from 1990 to 2000, and that this trend was likely to continue.

In February 2005, on the same day the Kyoto Protocol went into effect in 141 countries, the Mayor of Seattle announced that the Seattle community would commit to meeting the agreement's goals. Specifically, the Mayor committed Seattle to reduce greenhouse gas emissions by 5 percent from the level of emissions in 1990. The Mayor also announced plans to lead a "green" coalition of mayors for the next meeting of the U.S. Conference of Mayors.

Despite the City's significant efforts to reduce greenhouse gas emissions in Seattle, scientists predict that local or regional efforts to prevent or slow climate change are likely to be overwhelmed by the emissions produced worldwide by industrial and transportation activities. The International Panel on Climate Change indicated that even if all carbon dioxide emissions were eliminated immediately, climate change would continue through the 21st century because of persistent atmospheric greenhouse gases. A University of Washington climatologist predicted that current climate trends would continue for at least 10 to 20 years, regardless of new initiatives and efforts to reduce greenhouse gas emissions.

Seattle Department of Transportation Background

The Seattle Department of Transportation's mission is to deliver a safe, reliable, and efficient transportation system that enhances Seattle's environment and economic vitality. This broad mandate is reflected in the department's various functions and services, which range from building and maintaining current transportation infrastructure to envisioning and planning for future transportation systems that will enhance Seattle's quality of life.

SDOT is composed of seven functional divisions:

- **Executive Management**, which includes the Director's Office, as well as the human resources and communications functions;
- **Capital Projects and Roadway Structures**, which includes the Transportation Capital Improvement Program, and operation and maintenance of the City's bridges and other structures;
- **Street Use**, which provides permitting for all work to be performed in street rights-of-way;
- **Policy, Planning and Major Projects**, which is responsible for initiation of large projects and program development;
- **Resource Management**, which oversees the department's finances and provides information systems and administrative support;
- **Street Management**, which performs street resurfacing, cleaning and general maintenance; and
- **Traffic Management**, which is responsible for City street system operations, and neighborhood and operational programs.

These seven divisions are collectively responsible for the City's $8 billion transportation infrastructure, which includes Seattle's roadways, most bridges, and bike paths.

Scope and Methodology

This study presents high-level information to decision-makers on potential challenges facing the Seattle Department of Transportation (SDOT). We conducted this review to identify potential SDOT operations, services, or structures that could be significantly impacted by anticipated changes in the Pacific Northwest region's climate. Our review focused on primary impacts of climate change, such as warmer temperatures, rising sea levels, and increased winter precipitation. Our review did not consider potential secondary or regional transportation impacts (e.g., the potential impact of population influx on regional transportation, as climate in the Pacific Northwest is expected to become milder than in other regions as a result of climate change).

Our methodology included:

- Obtaining extensive testimonial information through questionnaires and interviews with SDOT officials;
- Compiling information from recent scientific studies on global and regional climate change;
- Verifying climate change data with local climate experts from the University of Washington;
- Interviewing a Seattle-based environmental consultant and City environmental staff to discuss local government efforts to understand and plan for the impacts of climate change;
- Creating an inventory of SDOT operations, services, and structures; and
- Assessing which SDOT operations, services, and structures could be impacted by climate change.

This study was conducted in accordance with generally accepted government auditing standards and standards for the professional practice of internal auditing.

Five Areas Could Be Impacted by Climate Change.

Climate change will impact SDOT in a variety of ways. Increased winter precipitation could lead to more flooding and landslides. Flooding and landslides impact mobility, worsen erosion around the footings of transportation infrastructures, and damage private and public property. Rising sea levels will require changes in design standards for seawall heights and bridge clearances. Increased precipitation and temperatures are likely to impact bridge operations and worsen deterioration of roads. Increased temperatures and longer summers will impact the condition of the City's urban forest.

Flooding and Landslides Could Increase[5]

Increased winter precipitation could cause Seattle creeks to flood more frequently, as well as increase landslide risks. Photo Source: Seattle Municipal Archives

Seattle has experienced two incidents of 100-year storms during the past eight years. Climate change could further increase winter precipitation, including the intensity of winter precipitation events, and cause more frequent flood and landslide events in Seattle. Floods and landslides can damage the City's transportation infrastructure and underlying utilities, and threaten public safety, mobility, and private and public property. Seattle Public Utilities generally has the primary responsibility for responding to emergencies such as landslides and surface flooding. However, SDOT is primarily responsible when the structural integrity of public streets, bridges, and retaining walls is threatened.

SDOT also shares an interest with Seattle Public Utilities in assuring that Seattle's drainage system will enhance and protect the City's investment in transportation infrastructure. Major storms during the winter of 1996–1997 caused more than 70 landslides with damage costs of $20 million. SDOT estimates departmental emergency response costs at approximately $25,000 per event.

According to department management, SDOT could readily respond to a limited increase in landslide incidents because sufficient staff and equipment are currently available. However, if Seattle experienced as many as 60 to 70 landslides in a one- or two-week period, the department would probably be required to allocate the entire Street Maintenance Division to landslide response efforts. SDOT (in coordination with Seattle Public Utilities) could also need to consider three related issues if landslide and flooding incidents became more frequent or severe: (1) the adequacy of existing drainage system capacity and design standards; (2) potential damage to roadway structures; and (3) impacts on water quality.

[5]For more detailed discussion on these areas, see Appendix 2.

Seawall Heights May Need Adjustments

The Alaskan Way Seawall replacement will need to accommodate a 0.9 foot rise in sea level.
Photo Source: Seattle Department of Transportation

Coastal inundation due to rising sea levels is one anticipated impact of climate change. A potential issue for the City to consider is whether its five seawalls, located along the Magnolia, West Seattle and downtown waterfronts, will adequately protect Seattle's shoreline. Standards for high-tide water levels used in the design of the City's existing seawalls are determined on a project-by-project basis. We reviewed an engineering report on the design of the replacement for the Alaskan Way Seawall, which is being overseen by SDOT, the Washington State Department of Transportation, and the Federal Highway Administration. Consulting engineers for the new seawall analyzed historical sea level data and predicted tide elevations for the structure's planned (design) life. The engineering report indicated that the design of the new seawall should accommodate a 0.9 foot rise in sea level over a 75-year time period.[6]

The University of Washington Climate Impacts Group indicated that this figure appears to be underestimated, and instead projected a rise of 1.0 to 2.8 feet over a 75-year period. Given the Climate Impacts Group's sea level projections, current seawall replacement design standards may not adequately account for the potential rise in sea level during the next century. SDOT should consider conducting further analysis to determine whether the standards for the seawall replacement design sufficiently address the projected rise in sea level.

SDOT officials indicated that sea level rise is a citywide concern that affects multiple departments, including Seattle Public Utilities, Seattle City Light, the Department of Parks and Recreation, and the Department of Planning and Development. If these departments develop independent projections of sea level rise, conflicting standards may be utilized in City policy decisions or capital project designs. SDOT officials suggested that an interdepartmental team could coordinate a comprehensive assessment of data on projections for sea level rise, as well as other issues related to climate change. The interdepartmental team would be responsible for identifying which sea level projections City agencies should utilize in establishing design standards or making policy decisions. However, SDOT officials indicated that the City could only revise existing standards or establish new standards to reflect changes in climate as long as the standards remained consistent with requirements established by funding agencies.

According to SDOT officials, City policy decisions on coastal inundation would determine any impact on the department's staffing and resource requirements. If the City chooses to prevent land along the shoreline from being lost to coastal inundation, more seawalls may be needed or existing seawalls may need to be replaced.[7] This would require SDOT to allocate more staffing

[6]"SR99: Alaskan Way Viaduct Project, Alaskan Way Seawall Wave Study," City of Seattle and Washington State Department of Transportation, September 2002.
[7]Building more seawalls could have negative impacts on coastal habitat for fish, birds, and aquatic plants.

and resources toward design of these structures. The department may need to redirect or increase staffing to monitor and perform maintenance for any additional structures constructed in the future.

Bridges Vulnerable to Temperature, Precipitation, and Sea Level Changes

Climate change could impact Seattle's bridge conditions as warmer temperatures cause greater thermal expansion. Structures can require increased ongoing maintenance if thermal expansion is not considered and accounted for adequately. If climate change causes temperatures to increase significantly, SDOT work crews may need to perform additional maintenance work to address increased expansion. SDOT management indicated that warmer temperatures could already be affecting the operations of some Seattle bridges. For example, openings have occasionally been delayed to allow bridges to cool. In addition, a warmer climate could result in more frequent detours and traffic disruptions on certain bridges.

Seattle Department of Transportation already monitors some bridges, such as the Admiral Way Bridge, due to erosion concerns.
Photo Source: Seattle Department of Transportation

Another concern related to bridge conditions is increased winter precipitation, which could exacerbate erosion. Due to erosion concerns, SDOT has monitored some bridges with shallow footings; these bridges may be even more susceptible to erosion if winter rainfall increases in the future.

A third concern related to climate change is how rising sea levels could affect bridge clearances. In particular, rising sea levels could impact clearances below the East Duwamish River Bridge (also known as the Duwamish River Bridge). As sea levels rise, the narrow clearance below the Duwamish River Bridge could be further reduced, and water or debris could reach the bottom of the bridge.

SDOT management indicated that it monitors bridge conditions closely. However, the department has not begun to consider how climate change could impact maintenance or resource requirements in the long term.

Roadways May Deteriorate More Rapidly

Increased winter rainfall and warmer temperatures, resulting from climate change, could restrict mobility by causing more rapid deterioration of the City's 1,500 lane miles of arterial streets and 2,700 lane miles of non-arterial streets. New specifications for concrete and asphalt mixes could potentially mitigate some of the anticipated changes in climate. SDOT managers expect that federal and state standards for concrete and asphalt mixes will be revised periodically to reflect changes in environmental conditions and that roadway replacement, which generally occurs on a

Increased rainfall could cause more rapid deterioration of pavement in City streets.
Photo Source: Seattle Municipal Archives

20- to 40-year cycle, will outpace changes in the region's climate. However, local climatologists raised the question of whether standards will be revised to reflect conditions projected over the lifetime of new road projects. Climatologists project increases in precipitation between 2 and 18 percent, and increases in temperature between 0.9 degrees and 4.7 degrees Fahrenheit by the 2020s, which is within the 20- to 40-year life span for a typical roadway.[8] The potential for climate change to cause more rapid roadway deterioration could make it even more important to perform adequate ongoing maintenance on older streets and minimize repair backlogs.

Increased rainfall could also cause more frequent or severe street flooding, which would impair mobility in Seattle's streets. SDOT management indicated that it has not considered impacts that climate change could have on roadway conditions, but the department works closely with Seattle Public Utilities to respond to the increasing demands on right-of-way drainage infrastructures to balance public health, safety, and welfare objectives.

Urban Forestry Already Impacted by Climate Change

SDOT maintains an inventory of 130 acres of land in City rights-of-way. Approximately 30,000 trees are located on the City-owned land and are valued at an estimated333 $100 million. Other landscaping (not including the value of the land) may be valued at an additional $25 million to $30 million.[9] According to the department's Senior Landscape Architect, Seattle may already be experiencing the impacts of climate change and should begin to plan a response.[10] The summers of 2003 and 2004 were dry, long, and hot, endangering the health of many plants and trees in Seattle.

Two consecutive long summers with hot and dry conditions endangered the health of many plants and trees in Seattle.
Photo Source: Seattle Department of Transportation

The Senior Landscape Architect currently considers climate change when planning and prioritizing maintenance of the department's landscaped areas. She indicated that if these trends continue, climate change could result in: (1) increased maintenance requirements for landscaped areas; (2) impacts on private and public development;

[8]Mote, P. W., et al. (2003). "Preparing for climate change: The water, salmon, and forests of the Pacific Northwest." Climatic Change 61: 45–88.
[9]These figures represent only the monetary value of the trees and landscape. They do not include other values, such as environmental benefits or shade provision.
[10]In addition, the Senior Landscape Architect cited the department's need to initiate watering contracts sooner to ensure that vulnerable landscaped areas are adequately maintained. This variance in scheduling is one indicator of longer and warmer summers during recent years.

and (3) fish habitat and water-quality concerns. Additional resources to provide and support landscaped areas could be needed to effectively address these issues.

Seattle Department of Transportation Is Beginning to Incorporate Climate Trends in Long-Range Planning.

The Seattle Department of Transportation (SDOT) is currently considering climate-related trends in the areas of urban forestry and the design for the new Alaskan Way Seawall, but has not yet considered climate change with regard to other infrastructure and operations. The department does not include climate change as a factor in its overall long-term planning. However, during our interviews, many of SDOT's division directors and managers recognized that climate change impacts would need to be considered in long-term planning and in future decisions. Department managers with responsibilities related to flooding, landslides, seawall, bridge, and roadway conditions, and urban forestry were able to identify ways that Seattle's transportation operations, services, and structures could be impacted by climate change.

This limited consideration of potential climate change impacts appears to be consistent with practices in other municipal transportation agencies. We conducted a survey of five cities and interviewed Seattle environmental policy staff and an environmental consultant to determine whether other jurisdictions have incorporated climate change into long-range planning.[11] Although some cities in the Pacific Northwest, including Seattle and Portland, have begun to study and assess how climate change could impact regional water resources, most jurisdictions have focused on developing preventive measures to reduce greenhouse gas emissions rather than identifying potential climate change impacts on other government services and infrastructure. None of the cities surveyed assessed how climate change would impact their transportation operations, services, and structures.

Boston Study Suggests That the Financial Impact of Climate Change Will Be Substantial for Local Jurisdictions.

A research team of policy and engineering experts from the University of Maryland, Tufts University, and Boston University concluded that climate change impacts on facilities, emergency services, and energy prices could impose costs of *$94 billion* on the Boston metropolitan area over the next 100 years. The research team issued its report, Climate's Long-Term Impacts on Metro Boston (CLIMB)[12] in August 2004.

According to the CLIMB report, the most significant climate change impact for Boston would be flooding caused by a sea level rise and heavy rains. These changes, however, are likely to occur slowly and would not be apparent until the late 21st century. More immediate impacts would be

[11]The audit survey included transportation planning departments for the cities of Cleveland, Dallas, Portland, San Diego, and San Francisco.

[12] The CLIMB Project was conducted over a five-year period and is the first detailed study of climate change impacts for a metropolitan area in the United States. The project was commissioned by the U.S. Environmental Protection Agency.

increased public health costs as a result of an increase in the incidences of heat waves in a city that is more adapted to milder summers.

The CLIMB project explored possible responses, incorporating various assumptions regarding policy decisions, demographic trends, economic conditions, and technological advances. The report concluded that the most costly approach for Boston and other cities to use is the "Ride It Out" approach in which no proactive steps are taken to prepare or respond to potential impacts. Funding would be used to respond to problems related to climate change as they occurred. According to the report, the best approach would be the "Green" approach, in which officials immediately begin to revise standards, plans and projects, and design and build upgrades based on revised standards as the existing infrastructure deteriorates.

Although the report did not provide a total cost comparison, the co-Principal Investigator from the University of Maryland estimated that the Ride It Out approach would be three times as costly as the Green approach. For example, river flooding in the Boston metropolitan area could cause $26 billion in damage under the Ride It Out approach, compared to $9 billion under the Green approach, or a difference of $17 billion.

Given climate change's potentially significant cost impact, the CLIMB report is an example of a farsighted approach to identify infrastructure and services in metropolitan areas that could be affected by climate change. The study could also aid local policymakers in planning proactive adaptive responses and strategies.

An Interdepartmental Team Could Assess Climate Change Impacts

Consistent with the comprehensive, integrated approach used in the CLIMB study, SDOT officials indicated that the City would benefit from establishing an interdepartmental team to assess potential climate change impacts. The interdepartmental team could also ensure the consistent use of scientific projections and data in developing City standards, policies, and long-range plans. The interdepartmental team would most likely require expert assistance to collect and analyze data as a basis for policy decisions by the Mayor and City Council, but the participating departments could share the costs associated with scientific research and analysis.

In addition, because climate change will have impacts beyond the City of Seattle, the City's interdepartmental team would benefit from inviting participation from or coordinating efforts with other regional agencies. This would provide a forum to begin considering how to address climate change impacts from a regional perspective.

Recommendations

The Seattle Department of Transportation should consider:

- Conducting further analysis to determine whether the standards for the seawall replacement design sufficiently address the projected rise in sea level; and

- Determining how climate change will be included in long-term planning related to flooding; landslides; seawall, bridge, and roadway conditions; and urban forestry.

The Executive should establish an interdepartmental team on climate change to:

- Ensure the consistent use of scientific projections and data in developing City standards, policies, and long-range plans;[13]

- Identify, prioritize, and quantify the potential effects of climate change impacts; and

- Plan appropriate responses to changes in the region's climate.

[13]This effort could be modeled on the successful technical and policy advisory teams developed during the early 1990s for the City's Environmental Priorities Project. These teams included experts from a broad range of local, regional, and state agencies and organizations.

APPENDIX 1
ANTICIPATED CLIMATE CHANGE IMPACTS AND AFFECTED SEATTLE DEPARTMENT OF TRANSPORTATION DIVISIONS

Observed and Projected Changes (Worldwide and Regional)	Potential Impacts on SDOT Services and Infrastructure	SDOT Divisions Primarily Affected
Temperature Increase: Pacific Northwest's average temperature increased 1.5 degrees Fahrenheit over the 20th century. Global average temperatures are projected to rise 3 to 10 degrees Fahrenheit between 1990 and 2100. Regional temperature is projected to rise approximately 2.7 degrees Fahrenheit by the 2020s and 4.1 degrees by the 2040s (compared to the 1990s).	▪ Dryer summers with warmer temperatures could threaten Seattle's landscaped areas. ▪ Bridge maintenance requirements could increase as warmer regional temperatures cause greater thermal expansion.	▪ Urban Forestry ▪ Capital Projects and Roadway Structures ▪ Street Maintenance
Increased Winter Precipitation and Streamflow: Precipitation in northeast Washington and British Columbia has increased approximately 14 percent since 1900. Scientists predict that there will be more winter rainfall in the 21st century. The October to March change in precipitation is expected to range between +2 percent and +18 percent by the 2020s, and between –2 percent to +22 percent by the 2040s. Scientists also project increasing intensity of rainfall events.	▪ Landslide incidents could increase with greater precipitation. Street access would be affected by an increase in landslides. Additional retaining walls could be needed in landslide risk areas. ▪ Increased soil erosion around transportation infrastructure supports, such as bridge footings. Roads could also become structurally unstable with subsurface erosion. ▪ If extreme storms occur more frequently, or rainfall increases beyond what the system is designed for, the drainage system could be overwhelmed. Potential redefinition of drainage design criteria will be needed.	▪ Street Maintenance ▪ Traffic Management ▪ Capital Projects and Roadway Structures

Observed and Projected Changes (Worldwide and Regional)	Potential Impacts on SDOT Services and Infrastructure	SDOT Divisions Primarily Affected
Decreased Summer Precipitation and Streamflow: During the last 50 years, peak spring runoff in western North America occurred 10 to 30 days earlier than in previous decades; the greatest advance in timing of spring runoff occurred in the Pacific Northwest. Streamflows into Pacific Northwest basins have declined and this trend is expected to continue. June streamflow in the Cedar River above Chester Morse Lake (Washington), as a fraction of annual flow has declined 8 percent since 1946 and is expected to decline further as a result of climate change.	▪ Two recent consecutive dry, hot, long summers endangered the health of many plants and trees in Seattle. ▪ If trends continue, maintenance requirements for landscaped areas could increase, impacting both private and public development. ▪ Reduced streamflows could harm fish habitat and cause concerns regarding water quality.	▪ Urban Forestry
Rising Sea Level: The global sea level has risen between four and eight inches over the past century. As the earth warms, the temperature of the seas increases, causing sea levels to expand. Melting glaciers and ice caps also contribute to a rise in sea level. The global sea level could rise 4 to 35 inches between 1990 and 2100. Some global climate models suggest an additional 8-inch sea level rise in coastal waters, such as the Puget Sound. Relative sea level rise is also affected by geological factors. Near Seattle, the land is subsiding at about 5.5 inches per century. Considering all of these factors, sea level near Seattle could rise 17 to 49 inches between 1990 and 2100.	▪ Local scientific research indicates that coastal flooding could occur more frequently and flood elevations could rise, disrupting or damaging low-lying properties and public infrastructure, including port facilities, roads, rail lines, tunnels, pipelines, and power lines. ▪ Rising sea levels will reduce bridge clearances; some Seattle bridges (e.g., East Duwamish River Bridge) already have shallow clearances. ▪ As Seattle's seawalls are replaced, new design standards will need to consider the projected rise in sea level. More frequent inspections of Seattle's seawalls may be needed.	▪ Capital Projects and Roadway Structures

APPENDIX 2
DETAILED ANALYSIS OF FIVE POTENTIAL AREAS OF CONCERN

Climate change will impact SDOT in a variety of ways. Increased winter precipitation could lead to more flooding and landslides. Flooding and landslides impact mobility, worsen erosion around the footings of transportation infrastructures, and damage private and public property. Rising sea levels will require changes in design standards for seawall heights and bridge clearances. Increased precipitation and temperatures are likely to impact bridge operations and worsen deterioration of roads. Increased temperatures and longer summers will impact the condition of the City's urban forest.

FLOODING AND LANDSLIDES

Many global climate models predict that climate change will bring increased winter precipitation and increased intensity of rainfall events to the Pacific Northwest region. Two problems that could occur with more rainfall are increased flooding and landslide risks. More frequent or more extreme flooding and landslides could cause extensive property damage, threaten roads and bridges, obstruct major transportation corridors, and interrupt public utilities and services. Seattle Public Utilities is generally the department with the primary responsibility for responding to emergencies such as landslides and surface flooding. However, SDOT is primarily responsible when the structural integrity of public streets, bridges, and retaining walls is threatened. The department also shares an interest with Seattle Public Utilities in assuring that Seattle's drainage system will enhance and protect the City's investment in transportation infrastructure.

Potential for Increased or More Extreme Flood and Landslide Incidents

Climate change could increase floods and landslide events, which can damage the City's transportation infrastructure and underlying utilities. Floods and landslides also threaten public safety, mobility, and private and public property.

One anticipated impact of climate change is increased rainfall, which could cause more incidents of flooding, particularly in Seattle's flood hazard areas along Thornton, Pipers, and Longfellow Creeks, the Duwamish Waterway in South Park, and the Puget Sound coastline.[14] These areas have a history of flooding, which prompted the channeling of the Duwamish River, and the construction of landfills and a downtown drainage system. Thornton, Pipers, and Longfellow Creeks continue to be vulnerable to flooding and erosion during rapid water-level rises due to heavy winter precipitation and runoff. These areas, which experienced significant flooding during major winter storms in 1996–1997 and October 2003, would be particularly vulnerable if winter rainfall increases as a result of climate change.

The City incurred costs totaling $36.3 million for extraordinary storm damage between 1995 and 2004, including costs associated with SDOT's emergency responses to flooding and three major

[14]Department of Planning and Development Memorandum 111, "Construction and Development in Floodplains," updated February 16, 2005.

landslide events. Major storms during the winter of 1996–1997 caused more than 70 landslides with $20 million worth of damage. The City received assistance from the Federal Emergency Management Agency and Federal Highway Administration to supplement SDOT emergency funds and other City funds. Although response costs can vary from $1,000 to $1 million depending on the event, SDOT estimates emergency response costs at $25,000 per event.

Increased Need for Emergency Response to Landslide and Flooding Incidents

An increase in landslides would have a significant impact on SDOT because of its important role in responding to landslide and flooding incidents that impact transportation infrastructure. While the department can defer responses to landslide events in non-emergency situations, emergency situations generally require an immediate response. According to the Pavement and Engineering Management unit's manager, the crew that clears streets to restore mobility following landslides could readily respond to a limited increase in landslide incidents because sufficient staff and equipment are currently available. However, if Seattle experienced as many as 60 to 70 landslides in a one- or two-week period, the entire Street Maintenance Division would probably be allocated to landslide response efforts by deferring other unit responsibilities, such as repairing pavement cracks and potholes.

The department's Traffic Management unit could also need to allocate additional staffing to close off streets, set up signage and barricades, and control traffic if SDOT is required to respond to more landslides and floods. Department management indicated that, although responses to emergency events could be significant, a more important consideration would be the potential for severe landslide events to cause roadway closures over prolonged periods or require capital improvements to ensure future mobility and safety.

Issues Related to Floods, Landslides, and Erosion That Could Require Attention

The City may also need to consider several issues related to flooding, landslides, and erosion, including:

- **Adequacy of Current Drainage System Capacity and Design Standards**: Increased rainfall could potentially overwhelm the existing stormwater drainage system and require expansion of the current drainage system's capacity. Parts of Seattle's drainage system already contain insufficient capacity and experience routine flooding during heavy rains. Inadequate drainage can also cause soil saturation and surface erosion, which contribute to landslides.

  Each municipality in the United States designs stormwater drainage and detention facilities to withstand storm events specific to its geographic location, such as a statistically modeled 100-year storm. A 100-year storm is a storm of intensity and duration that has a 1 percent (one in 100) chance of occurring in any given year based on statistical modeling. Seattle has experienced two incidents of 100-year storms during the past eight years. If climate patterns show that severe storm events are occurring more frequently or become more intense as a result of climate change, local design standards may need to be reviewed and innovative methods may need to be developed to accommodate greater volumes of stormwater.

Seattle Public Utilities' Resource Planning staff indicated that installing natural drainage systems (such as pervious materials, swales, ponds, and vegetation) in City rights-of-way could become even more important given potential future drainage requirements. These natural drainage techniques reduce runoff into the City's drainage system, potentially mitigating the need to expand or build additional drainage facilities while providing the additional benefits of increasing the City's green areas. However, increased use of natural drainage systems in the City's rights-of-way could compete with mobility and other transportation priorities. If climate changes as predicted and drainage requirements increase, policy-makers may need to consider how to manage the rights-of-way to best meet public objectives.[15]

- **Potential Damage to Roadways and Structures:** Increased precipitation and flooding will potentially exacerbate erosion of soil around roads, bridge footings, and retaining walls, and threaten the stability of the City's existing roads, bridges, retaining walls, and stairways. Older concrete structures (such as retaining walls and stairways) with shallower footings are at greater risk of failure from erosion, as well as from increased moisture filtering into cracks.

- **Impacts to Water Quality**: Increased runoff and erosion can also cause impacts to water quality. The increased incidences of landslides, erosion, and associated flooding could direct more pollutants into the region's streams, lakes, and other bodies of water. These water-quality concerns are significant because of their impacts on salmon and other fish and wildlife.

Current Status

In 2000, the Shannon and Wilson consulting firm completed the *Seattle Landslide Report*, a study on Seattle landslide history and risks. According to the Shannon and Wilson study, Seattle suffers more damage from landslides than most other large cities in the United States, with the exception of coastal California. Recent U.S. Geological Survey studies indicate that Seattle's landslide activity is closely associated with heavy rainfall during a three-day period following significant rainfall over the preceding 15-day period. If global climate models are accurate, these major storm events could become more common. In fact, during the past eight years, the City has experienced two 100-year storm incidents.

Although SDOT managers indicated that the department has not begun to consider climate change in long-range planning, the City established a landslide mitigation program to take proactive steps to protect public facilities in landslide-prone areas following the severe landslides during the winters of 1995–1996 and 1996–1997. Beginning in 1999, SDOT initiated a series of engineering studies to develop a preventive program to protect public facilities in landslide-prone

[15]In spite of the potential impact of climate change on drainage system requirements, Seattle Public Utilities staff indicated that land use is a more significant determinant in the design, capacity, and location of drainage facilities. This is because drainage facilities must accommodate substantially more water in developed areas due to runoff from impervious surfaces. Even if the City increased its use of natural drainage systems in public rights-of-way, runoff from private property would still be a driving factor in determining the overall drainage system requirements.

areas.[16] In January 2000, the department conducted a risk assessment of City arterial streets to identify preventive maintenance and repair projects for arterial street segments in landslide areas.[17]

Recently, the department has worked closely with Seattle Public Utilities, the City Budget Office, the Department of Planning and Development, and the Department of Parks and Recreation to develop a matrix to prioritize landslide mitigation projects to protect City-owned facilities.[18] Since then, one high-priority landslide mitigation project has been completed, and other high-priority projects are in the planning and design processes. SDOT officials indicated that the assessments do not consider risks on a long-term basis, so climate change was not considered in these studies. Because SDOT does not have sufficient budgetary resources to invest in long-term landslide mitigation projects, it has begun monitoring street movement at certain locations and making short-term repairs to enhance public safety.

SEAWALL CONDITIONS

Global climate models predict that sea levels will rise globally as a result of thermal expansion and melting glaciers and ice caps. A University of Washington climate impacts study estimated that the sea level rise would range from four to 35 inches globally by 2100, with a more rapid increase in the Pacific Northwest.[19] Rising sea levels could result in coastal inundation and could impact the conditions of land adjacent to major bodies of salt water.

Additional Seawalls May Be Needed to Protect Shorelines from Coastal Inundation[20]

Erosion caused by rising sea levels could increase the risk of landslides near the shore. The City owns and maintains five seawalls that help protect Seattle's shoreline, along waterfronts in Magnolia, West Seattle, and downtown Seattle. Before these seawalls were constructed, the base of the bluffs and slopes along the Puget Sound coastline were subject to constant erosion, causing the lower part of the slope to slide and undercut the slope's higher elevations. With the construction of seawalls and other shoreline protection measures, erosion has been arrested or greatly reduced.

The Shannon and Wilson *Seattle Landslide Report* indicated that these slopes have not necessarily achieved a stable configuration, so landslides could still occur, particularly along bluffs that are not protected by seawalls (such as Magnolia Bluff). Generally, the severity of

[16]These studies were the "Retaining Wall Drain Inventory Study," "Retaining Wall Inspection Services," "Landslide Risk Assessments," and "Slope Reconnaissance in High-Priority Sites from the Landslide Risk Assessment Study."
[17]Risk Assessment for Slope Hazard, Phase I – Arterial Streets, January 21, 2000 by AGRA Earth and Environmental, Inc.
[18]The matrix considers all City-owned properties, and prioritizes mitigation projects based on potential improvements to public safety; importance and vulnerability of City facilities, likelihood and potential size of slide events, inconvenience to people and commerce, slope modification, potential for public-private partnering on projects, maintenance requirements, and economic feasibility.
[19]Mote, P. W., et al. (1999). *Impacts of Climate Variability and Change, Pacific Northwest*. National Atmospheric and Oceanic Administration, Office of Global Programs, and JISAO/SMA Climate Impacts Group, Seattle, WA: p. 110.
[20]Building more seawalls could have negative impacts on coastal habitat for fish, birds, and aquatic plants.

increased erosion is a result of a combined function of the amount of sea level rise and winds. If the sea level rises up to an additional foot, the increase will not have a significant impact on slope stability. However, if the sea level increased by more than a foot, additional seawalls could be needed to protect Seattle's shorelines.

Department planners and engineers indicated that newly constructed seawalls could need to be stronger, higher, or both, to accommodate higher water levels and stronger tide forces in the future. One manager in the Capital Projects and Roadway Structures Division speculated that seawalls could also be designed to be raised in the future, with extra support at the base to accommodate any future increases in height. This approach would be costly, but may extend the useful life of the structure.

Alaskan Way Seawall Replacement Design Standards Consider Rising Sea Level

Water-level design standards for the City's seawalls are determined on a project-by-project basis. Project standards are based on location-specific historical water level data for a 14-year span; amount of exposure (e.g., to predominant wind forces); and location and infrastructure priority (i.e., minor structure versus a major structure supporting an arterial). SDOT officials considered a rising sea level in developing design standards for the Alaskan Way Seawall replacement project. Department officials determined that the current seawall height is adequate to accommodate the sea level increase projected in consultant reports, with exceptions in only a few locations.

The 2002 Parsons, Brinckerhoff, Quade and Douglas *Alaskan Way Seawall Wave Study* on the project design criteria for waves, currents, and water surface elevations analyzed historical sea level data and predicted tide elevations for the structure's planned (design) life. The consultant study indicated that there is a 10 percent probability that a rise in sea level would exceed 1.6 feet, a 50 percent probability of exceeding 0.9 feet, and a 90 percent probability of exceeding 0.4 feet by year 2075. The study recommended that the design of the new seawall should accommodate a 0.9 foot increase in sea level over a 75-year time period.[21] In addition to the predicted sea level rise over the next 75 years, the consultant study also considered the highest tides during extreme storm events and storm surges.[22]

The University of Washington Climate Impacts Group indicated that this figure appears to be underestimated, and instead projected a rise of 1.0 to 2.8 feet over a 75-year period. Given the Climate Impacts Group's sea level projections, current seawall replacement design standards may not adequately account for the potential rise in sea level during the next century. SDOT should consider conducting further analysis to determine whether the standards for the seawall replacement design sufficiently address the projected rise in sea level.

[21]The predicted sea level rise was calculated based on methodology from a 1995 U.S. Environmental Protection Agency report ("The Probability of Sea Level Rise") that estimated future sea level at particular locations. The report was based on a compilation of results from numerous scientific studies, including an assessment from a scientist who doubts that greenhouse gases will substantially increase global temperatures.

[22]The consultant report recommended a maximum water surface design elevation that allows approximately 3.8 feet of freeboard (clearance) from the extreme high-tide water surface level to the top of the seawall.

SDOT officials indicated that sea level rise is a Citywide concern that impacts multiple departments, including Seattle Public Utilities, Seattle City Light, the Department of Parks and Recreation, and the Department of Planning and Development. If these departments develop independent projections of sea level rise, conflicting standards may be utilized in City policy decisions or capital project designs. SDOT officials suggested that an interdepartmental team could coordinate a comprehensive assessment of data on projections for sea level rise, as well as other issues related to climate change. The interdepartmental team would be responsible for identifying which sea level projections City agencies should utilize in establishing design standards or making policy decisions. However, SDOT officials indicated that the City could only revise existing standards or establish new standards to reflect changes in climate as long as the standards remained consistent with requirements established by funding agencies.

Impact on Seattle Department of Transportation Engineering and Design Staff

According to SDOT officials, City policy decisions on coastal inundation will determine the department's actions, staffing, and resource requirements. To protect the coastline and lowlands from being lost to coastal inundation, more seawalls may be needed or existing seawalls may need to be replaced. This would require SDOT to allocate more staffing and resources toward design and capital improvement projects. The Roadway Structures Design Supervisor indicated that the department does not have sufficient staffing to perform all of its current design work in-house, and has hired outside consultants to meet design needs; this trend would most likely continue if additional major projects were implemented. The department could also need to increase staffing to monitor and perform maintenance for any additional structures constructed in the future.

Current Status

With the exception of the Alaskan Way Seawall, which is inspected annually for movement, SDOT's Capital Projects and Roadway Structures Division does not have the capacity to routinely inspect the City's seawalls. Instead, seawalls are monitored on an as-needed basis.

BRIDGE CONDITIONS

Some of Seattle's 105 bridges could be impacted by the anticipated changes in climate. According to the 2004 *Report of the Citizens' Transportation Advisory Committee*, 37 percent of the bridges are in "poor condition or worse," with 4 percent already facing weight restrictions due to critical deficiencies. Anticipated changes in the region's climate (such as increased precipitation, rising sea levels, and warmer temperatures) could create additional concerns regarding bridge conditions, and increasing bridge maintenance may become even more important.

Older Bridges Could Face Erosion and Paving Problems Due to Increased Precipitation

Increased winter precipitation running off hillsides could cause concerns related to erosion around some City bridge footings. According to SDOT's Bridge Maintenance Engineering Supervisor, erosion could be problematic around bridges with shallower footings, such as bridges

located at Admiral Way, Howell Street, 15th Avenue Northeast and Northeast 105th Street, Queen Anne Drive, McGraw Street, and the Magnolia Bridge. SDOT has monitored these bridges and responded to erosion concerns in the past; these bridges may be even more susceptible to erosion if winter rainfall increases in the future.

Increased precipitation could also impact the condition of bridges' paving as increased rainfall over prolonged periods could cause more water to filter into asphalt and reinforced concrete structures, resulting in more rapid deterioration. SDOT could be required to increase maintenance, respond more frequently to potholes, or replace concrete and asphalt structures more frequently.

Rising Sea Levels Could Reduce the Duwamish River Bridge Clearance

The East Duwamish River Bridge could be impacted by rising sea levels because the river's water level is affected by water flowing from Elliott Bay. The river could also rise during winter due to increased precipitation running into receiving water bodies. The Civil Engineering Supervisor indicated that the current clearance between high tide and the bottom of the bridge is already quite narrow. If the level of the river rises even farther, water and debris could reach the bottom of the bridge.

Warmer Temperatures and Thermal Expansion May Increase Maintenance Requirements

Bridges are designed to accommodate thermal expansion and contraction. According to the Civil Engineering Supervisor, if climate change causes regional temperatures to increase significantly, SDOT's crews may need to perform additional maintenance work to increase the structural gaps that allow bridges to accommodate thermal expansion.

The department's maintenance crews measure gaps in bridge expansion joints during periods of cold and hot weather to determine whether structures are reacting as expected. The Civil Engineering Supervisor indicated that some of Seattle's bridges have already shown some signs that warm temperatures are impacting their structures. For example, a railing piece on the University Bridge grates against other pieces during particularly hot periods, which requires increased maintenance to provide adequate expansion space. The department has delayed openings on some bridges until they have cooled. The department's Structure Maintenance and Operations Manager indicated that a warming climate could result in more frequent detours and disruptions to traffic flows on routes requiring passage over certain bridges.

Thermal expansion could also damage the paved surfaces on Seattle's bridges. Thermal expansion could cause concrete panels on the bridge approaches to expand and grate against the bridge.

Current Status

As noted above, of the 105 City-owned and maintained bridges, 37 percent are in poor condition or worse and most are more than 60 years old. The 2004 *Report of the Citizens' Transportation Advisory Committee* notes that current funding allows replacement or major rehabilitation of one

bridge every three or four years instead of the optimal replacement rate of one bridge per year. Maintenance delays cause the costs of replacement or a major rehabilitation to increase substantially, effectively doubling every 10 to 15 years. Some of the anticipated changes in climate could cause more rapid deterioration, making it even more costly to maintain, repair, or replace Seattle's bridges. Although SDOT management closely monitors the current bridge conditions, the department has not begun to determine how changes in the region's climate may exacerbate bridge conditions and affect resource requirements in the long term.

ROADWAY CONDITIONS

SDOT maintains approximately 1,500 lane miles of arterial streets and 2,700 lane miles of non-arterial streets. Climate change could contribute to pavement deterioration and street flooding, potentially impairing mobility more frequently in the future. Increased winter rainfall and warmer temperatures could also cause an increase of potholes and the cracking and buckling of paved surfaces, according to some SDOT managers. In addition, increased winter rainfall could potentially overwhelm the City's drainage system and result in increased localized flooding incidents.

Street and Pavement Conditions Could Worsen with Climate Change, but Changes in Asphalt and Concrete Mixes May Mitigate Impacts

According to SDOT's 2004 *Pavement Condition Report*, decades of underinvestment have resulted in a growing backlog of deferred maintenance, which may eventually have an adverse impact on Seattle's economy and quality of life. Seattle's streets have a pavement replacement value of approximately $4.1 billion.

According to the 2004 *Report of the Citizens' Transportation Advisory Committee*, 16 percent of the City's arterial streets are in poor condition or worse. Seattle's streets could degrade even more rapidly if the region experiences heavier winter rainfall and warmer summers that many scientists predict. SDOT managers indicated that increased rainfall could cause streets to deteriorate more rapidly, because the water would filter underneath the street pavement, resulting in more cracks and potholes that require repair. Wetter winters could also reduce the available workdays for SDOT paving crews, making it more difficult to respond effectively to concerns about street conditions.

Another concern related to climate change is the impact that warmer temperatures have on pavement. During periods of sustained hot weather, pavement can soften and buckle, resulting in localized, upward displacement of street surfaces (or "heat bumps"). Prolonged hot weather produced heat bumps on a section of Interstate-90 during the summer of 2004. Although the frequency of these occurrences is a function of pavement design and maintenance, longer and warmer summers could result in increased heat bump incidents with an associated increase in design and maintenance costs.

According to a SDOT Senior Civil Engineer, the City recently began using a new asphalt mix to comply with federal funding requirements. The new asphalt mix has a 20-year life cycle and

performs better in warmer temperatures. This recent change could potentially mitigate some of the potential impacts that warmer temperatures have on roadway conditions.

Although the design and management of new roadway infrastructure may change as a result of potential changes in climate, the Pavement Engineering and Management unit indicated that roadways, which have a 20- to 40-year life span, are being replaced on a time frame that outpaces climate trends. The unit also expects that federal and state construction standards will continue to be revised to reflect changes in environmental conditions. However, local climatologists project an increase in precipitation between 2 and 14 percent by the 2020s, which is within the 20- to 40-year life span for a typical roadway.[23] The potential for climate change to cause more rapid roadway deterioration could make it even more important to perform adequate ongoing maintenance and minimize repair backlogs.

Drainage Problems and Street Flooding May Increase

Climate change could also cause winter rainfall to increase, potentially resulting in more frequent or severe street flooding and impairing mobility in Seattle's streets. If winter rainfall increases as expected, the adequacy of the City's drainage systems could pose an additional concern to the roadway infrastructure. As mentioned previously, Seattle has experienced two incidents of 100-year storms in the past eight years. If storms with greater intensity or duration began to occur more frequently, the City's drainage systems could be required to manage a greater capacity. SDOT management indicated that the drainage system is adequate under current conditions, but could be overwhelmed by an increase in precipitation.

SDOT indicated that efforts to prevent the drainage system from being overwhelmed could include improving maintenance of existing stormwater drainage facilities, enhancing stormwater and flood control maintenance efforts (such as increasing drainage infrastructure inspections), and supporting ongoing City efforts to develop innovative natural drainage systems. The department indicated that it is already working closely with Seattle Public Utilities to respond to the increasing demands on right-of-way drainage infrastructures to balance public health, safety, and welfare objectives.

Current Status

Overall, the City's arterial streets are in good condition. However, the City's *Pavement Condition Report* indicates that the backlog of repair and resurfacing may eventually have a negative impact on Seattle's economy and quality of life. Seattle's deferred pavement maintenance is estimated to be approximately $310 million and could increase to $560 million within ten years. Climate change impacts could potentially cause the City's pavement to deteriorate at a faster rate, which could result in an increased need for maintenance and repair response.

[23] *Implications of Global Climate Change for the Pacific Northwest,* December 15, 2004, Seattle Urban Sustainability Advisory Panel, Amy Snover, Ph.D., University of Washington Climate Impacts Group.

URBAN FORESTRY

Seattle may already be experiencing the impacts of climate change and should begin to plan a response to protect the City's landscaped areas, according to SDOT staff. The department's Urban Forestry unit maintains an inventory of 130 acres of land in City rights-of-way. Approximately 30,000 trees are located on the City-owned land and are valued at an estimated $100 million. Other landscaping (not including the value of the land) may be valued at an additional $25 million to $30 million.[24]

The last two summers have been dry, long, and hot, endangering the health of many plants and trees. If these trends continue, climate change could result in: (1) increased adverse impacts to trees and landscaped areas; (2) potentially higher costs for private and public development; and (3) deterioration of fish habitat and water quality. Additional resources to provide and support landscaped areas would be needed to effectively address these issues.

Increased Adverse Impacts to Trees and Landscaped Areas

According to SDOT's Urban Forestry staff, the anticipated warmer regional temperatures and reduced summer precipitation are likely to increase stress on the City's trees and landscaped areas, causing these assets to deteriorate and require increased maintenance to preserve SDOT's investment. These impacts are likely to result in:

- Trees becoming more susceptible to disease and insect infestation;
- Increasing growth of noxious weeds, which may overwhelm native vegetation in a state of decline; and
- Need for more frequent watering of vulnerable trees and landscapes.

Urban Forestry staff also indicated that approximately 50 percent of the City's landscaped areas are currently rated in good condition, while the remaining 50 percent are in fair to poor condition. The high percentage of landscaped areas in poor or fair condition has resulted from an increase in the number of landscaped sites being installed with no corresponding increase in maintenance resources. Although many older landscaped areas are rated as fair or poor and would benefit from increased maintenance, the Urban Forestry unit has needed to prioritize its resources to focus on maintaining newer landscaped areas to protect younger, more vulnerable plants and trees.

Potentially Higher Costs for Private and Public Development

Warmer, drier summers could also impact construction and development in Seattle. Both public and private development costs may increase as it becomes more costly to meet City requirements to establish and maintain plants installed in the rights-of-way. Sufficient irrigation and monitoring are particularly important to help young trees planted in the rights-of-way become established. The industry standard for providing supplemental water for new landscaped areas could increase from three to five years to five to eight years as a result of climate change. Costs

[24]These figures represent only the monetary value of the trees and landscape. They do not include other values, such as environmental benefits or shade provision.

may also increase due to the need to protect established, mature, but vulnerable trees. This additional support would increase landscaping costs for both public and private development projects. In addition, reduced spring and summer streamflow may also cause the cost of water to increase when irrigation is most necessary, and greenery may become more expensive as it becomes more difficult to grow. These cost trends could have negative financial impacts on development.

Deterioration of Fish Habitat, and Water and Air Quality

Combined with fewer thriving trees and landscaped areas, climate change could cause Seattle's stream temperatures to rise and harm the region's fish populations. Because water running into streams from landscaped areas is cooler than water from paved surfaces, the loss of trees and landscaped areas will result in warmer water entering streams from paved surfaces. Air quality may also be affected by loss of trees because trees cool the air, trap particulates, and produce oxygen. According to Urban Forestry staff, adequate trees and greenery will become even more critical in maintaining water and air quality.

Current Status

The Urban Forestry staff believes that Seattle's climate may already be changing, and they are currently implementing some strategies for the City to maintain its trees and landscaped areas adequately. For example, climate change is already considered in the design of new landscapes, which emphasize drought-resistant plants. Urban Forestry staff indicated that, with additional resources, more trees could be planted and existing landscaped areas could be better maintained to increase tree canopy and groundcover and provide a greater cooling effect. In addition, an interdepartmental effort is currently underway to develop and implement an urban forest management plan. The plan's overall objective is to ensure that City departments implement best practices to preserve and enhance green infrastructure, and to mitigate the negative effects of climate change.

APPENDIX 3
CLIMATE'S LONG-TERM IMPACTS ON METRO BOSTON (CLIMB) MEDIA SUMMARY

We are grateful to the authors of the report on *Climate's Long-Term Impacts on Metro Boston* for granting permission to include this media summary in our report. The authors, listed below, acknowledge the support and assistance of the National Environmental Trust in preparing this media summary.

- **Paul Kirshen**, Ph.D., M.S., B.S., Research Professor, Tufts University, Department of Civil and Environmental Engineering and Fletcher School of Law and Diplomacy

- **Matthias Ruth**, Ph.D., Roy F. Weston Chair in Natural Economics, University of Maryland, School of Public Policy

- **William B. Anderson**, Ph.D., Professor and Associate Chairman, Boston University, Department of Geography

Climate's Long-term Impacts on Metro Boston (CLIMB)

Media Summary

Authors:

Paul H. Kirshen
Tufts University

William P. Anderson
Boston University

Matthais Ruth
University of Maryland

Major Impacts by 2100 of Climate Change on Metropolitan Boston

- During the 21st century, sea level along metropolitan Boston's coastline could rise at least 24 inches (0.61 meters)
- Higher sea levels of just 12 inches or more could give a typical 10-year storm the intensity of the present 100-year storm; similarly, a 100-year storm would hit with the intensity of the present 500-year storm
- Property damage from coastal flooding, plus the cost of emergency services, could total $94 billion during this century
- Homeowners in metropolitan Boston's 100- and 500-year floodplain could sustain flood damage averaging between $7,000 and $18,000 per home
- Boston could face at least 30 days of temperatures above 90∞F, more than double the current number. Mortality rates tend to rise in Boston when temperatures exceed 90° F.
- By 2030, the average number of days in July requiring air conditioning could increase by over 24% with a corresponding rise in energy use.
- Global warming will reduce water quality in rivers and streams making parts of them uninhabitable for fish and aquatic plants.
- During and immediately after extreme weather events, motorists could spend an estimated 80% more hours on the road due to traffic delays; likewise, 82% more trips could be cancelled because of road flooding.
- River flooding related to global warming is expected to impact twice as many properties and double the overall cost of damage during this century.
- Water systems relying totally upon local supplies may need to draw on the Massachusetts Water Resources Authority system to supplement their supplies to maintain acceptable local water service affected by climate and demographic changes.

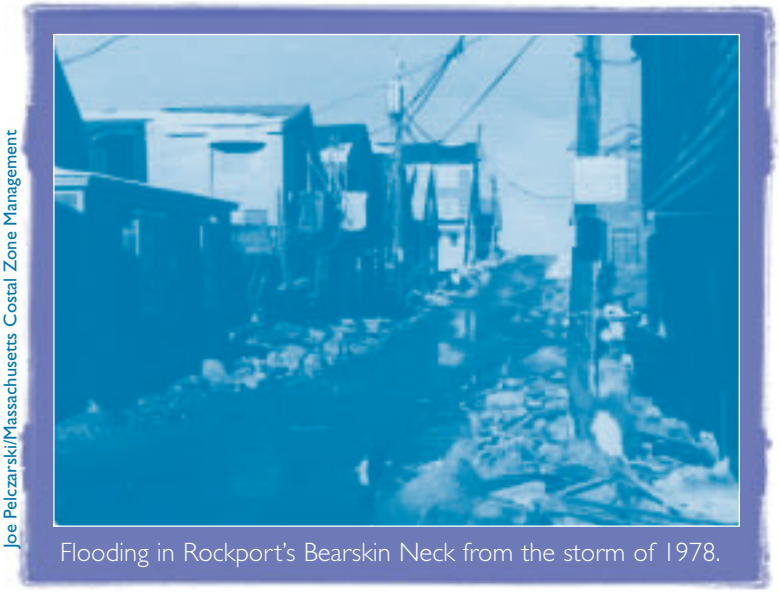
Overview

After more than 20 years of research and analysis, scientists now agree on the fundamental causes of greenhouse gas emissions and their effect on the Earth's atmosphere. Increased releases of carbon dioxide and methane, among other global warming gases from fossil fuels burned to generate energy, are accumulating in the lower atmosphere, trapping the sun's heat, and raising surface temperatures on earth. In the last century, scientists detected a distinct warming trend of 0.8° Fahrenheit. Based on the rate of increase and other calculations, the climate models used by the CLIMB study predict a rise in average temperatures for metropolitan Boston of between 3° C and 5° C (6–10° F) by the end of this century. Higher temperatures will produce a number of related effects:

- Higher sea levels in 2100 of between 24 inches and 39 inches due to the combined effects of increases in ocean volume, melting land ice, and land subsidence
- More coastal flooding from higher sea levels and continuing land subsidence
- More inland flooding from rainfalls
- Loss of wetlands and estuaries
- Greater energy demand, primarily for summertime cooling
- Higher concentrations of air pollution
- Increased public health problems from unprecedented high temperatures

Not all regions of the world face the same impacts from climate change, but regardless of their geographical and climatalogical situation, some type of effect from moderate to extreme will be felt.

As an immediate step toward solving this problem, governments, businesses, and individuals must reduce releases of greenhouse gases. Many entities and institutions are already lowering energy use by switching to renewable or less polluting alternative sources and by becoming more energy efficient. These mitigation initiatives have both immediate and long-range benefits, making them attractive, "no-regrets" options.



Joe Pelczarski/Massachusetts Costal Zone Management

Flooding in Rockport's Bearskin Neck from the storm of 1978.

Until fairly recently the debate has focused on determining (a) the causes and rate of climate change, (b) the extent and degree of potential impacts, and (c) the best strategies to mitigate greenhouse gas emissions. Now researchers, assuming the likelihood of climate change, have begun to consider a variety of adaptation strategies. Even within highly industrialized countries, possible impacts and responses vary widely. While there are generalized predictions of the likely consequences of global warming to specific regions of the U.S., until now no jurisdiction has yet developed a plan for adapting to these impacts.

The CLIMB Project

For the first time, a group of experts has compiled a comprehensive analysis of adaptive actions by a major metropolitan area to pre-empt some of the worst effects of climate change. *Climate's Long-Term Impacts on Metropolitan Boston (CLIMB)* describes how global warming could impact a major U.S. coastal city, what those impacts are likely to cost, and what adaptive measures can be taken to protect the region from the worst of these effects. This study culminates a four-year, one million dollar research effort, funded by the United States Environmental Protection Agency (EPA), and conducted by 10 experts at Tufts University, the University of Maryland, and Boston University in consultation with officials from the EPA, the State of Massachusetts, the Metropolitan Area Planning Council, and local government officials throughout the Boston metropolitan region.

What Is CLIMB?

CLIMB is a multi-sector analysis of how global warming will affect some of the key socio-economic activities typical in major urban centers. CLIMB demonstrates how global warming could fundamentally affect the Boston region over the next century, requiring tens of billions of dollars to adapt to changes and to repair climate-related damages.

The study tests overall monetary and environmental costs for three adaptive strategies:

- "Ride-It-Out" assumes no adaptive steps will be taken to ameliorate the effects of global warming except rebuilding residential and commercial property and public infrastructures after they are damaged by climate-related flooding and other weather-related events. Of the three options, this is the most expensive [p. 58].*

- "Build-Your-Way-Out" assumes limited pre-emptive actions, such as coastal protection by "hardening" shorelines with sea walls, bulkheads, etc., to limit the effects of global warming. In most locations, this is the second most costly scenario [p. 58].

- The "Green" scenario assumes fairly aggressive pre-emptive actions to blunt the effects of global warming. This includes new building codes for greater energy efficiency, early warning systems in anticipation of extreme high temperatures, and, above all, steps to minimize the effects of flooding in metro Boston's coastal plain. In addition, the Green scenario assumes that all new structures in the

* Page numbers in brackets refer to the corresponding page in the full CLIMB study.

> 100- and 500-year floodplains are completely flood proofed when they are built and that existing buildings are flood proofed at the time of sale. In the majority of locations the cost of this scenario is the lowest of the three, while its environmental benefits are the highest [p. 59].

Doing nothing to prepare for climate change will result in the greatest amount of damage and the highest possible costs to governments and residents in the Boston region. In contrast, investing now in measures to adapt to and protect against the changing climate will significantly reduce the amount of damage from global warming and lower the costs of adaptation. Above all, CLIMB provides a blueprint for elected officials and policy makers to understand and evaluate their options for protecting key assets from the consequences of global warming.

What's New about CLIMB?

To date, the bulk of climate change research has concentrated on the causes of global warming and strategies to mitigate climate change by reducing of greenhouse gas emissions. CLIMB is the first study to take this research to the next level by analyzing how a major urban area can adapt to fundamental and far-reaching changes that will inevitably occur due to global warming. For the purpose of this study, metropolitan Boston comprises over 100 municipalities in six counties [p. 22, Table 7.1]. Unlike many other global warming studies, however, CLIMB is more than simply a report; it is a dynamic tool that can be used by government officials, business leaders and others to develop and deploy the most cost effective measures for protecting critical economic and social assets from disruptive climate change.

Joe Pelczarski/Massachusetts Costal Zone Management

1978 storm damage to Rockport Harbor.

Why Is CLIMB Important?

The quality of life and long-term economic success of metropolitan regions such as Boston depend heavily on the reliability of their infrastructures. Transportation and communication networks, for example, provide mobility of people, goods, and information; power plants and energy distribution systems provide energy essential for homes, businesses, and industries; and water supply, drainage, flood management, and waste water treatment systems provide water to consumers, protect homes and businesses from flooding, and ensure treatment of effluents to minimize adverse environmental and health effects from pollution.

The higher the levels of economic activity, the more important are the quality and reliability of infrastructure systems. These links are especially critical in urban areas. Disruptions to infrastructures can have far-reaching implications both for the public welfare and for the regional economy. Flooding in the fall of 1996, for example, inflicted heavy damage on parts of metro Boston. According to the *Boston Globe*, the storm

"flooded powerful institutions such as the Museum of Fine Arts and Northeastern University, wreaked havoc on the Green Line's Kenmore Square station, and caused $70 million in property damage." In the summer of 1999, New England's power grid nearly collapsed because of unprecedented demand on electricity in response to record high temperatures [Carlos Monji, Jr., "Region Swelters in Record Heat," The *Boston Globe*, June 8, 1999].

Boston's Vulnerability to Global Warming

Recent research on the effects of global warming in metro Boston shows that sea level will rise, peak summer temperatures will be higher, seasonal energy demand will shift, and the frequency and intensity of severe winter and summer storms will increase. Infrastructures are designed according to the prevailing socioeconomic and environmental conditions at the time of planning and construction, and thus are very sensitive to climate. Sustained changes in climate and weather may affect the ability of existing infrastructure to provide reliable services and may require costly adjustments or repairs to remain viable.

Most infrastructures have a lifetime of many decades–parts of the Boston subway and sewer system are more than 100 years old. Upgrading or substituting infrastructures can also take many years, as the "Big Dig" illustrates after more than a decade of work and a cost of $14.6 billion. Being able to anticipate today what the climate-induced impacts may be on existing and future infrastructure is therefore vital for planning and investment decisions.

Getting policy-makers to focus on long-range planning, however, presents a challenge. In response, CLIMB provides the pathways for public officials to make decisions that employ the most efficient and effective choices in dealing with the long-term consequences of climate change.

Key Findings

CLIMB presents key findings in seven areas of public welfare and infrastructure: sea level rise, river flooding, public health, water quality, energy, transportation, and water supply.

COASTAL AND RIVER FLOODING

Flooding relates directly to all aspects of metro Boston's infrastructure. It can seriously damage the built environment, paralyze transportation, interrupt energy distribution, and impair wastewater treatment, posing threats to the economy of the region and the health of its inhabitants. Metro Boston faces an especially high risk of coastal and river flooding because of its long coastline, numerous rivers and streams, concentrated coastal development, and high exposure to heavy rainstorms, hurricanes and nor'easters.

Sea Level Rise

The Problem

Sea level rise in the Boston coastal zone, encompassing 32 municipalities with a combined population of 1.2 million, will lead to more severe and frequent flooding events [p. 54]. During the past century, land subsidence and sea level rise resulted in a 0.3 meter (slightly less than 1 foot) relative increase in sea level [p. 55]. During the 21st century, according to projections of the Canadian Climate Center, continued

Kelly Knee, Applied Science Associates, Inc.

"Current mean sea level in Boston (2000). This computer graphic shows current conditions with Boston harbor in the foreground and the Charles River in the background.

Kelly Knee, Applied Science Associates, Inc.

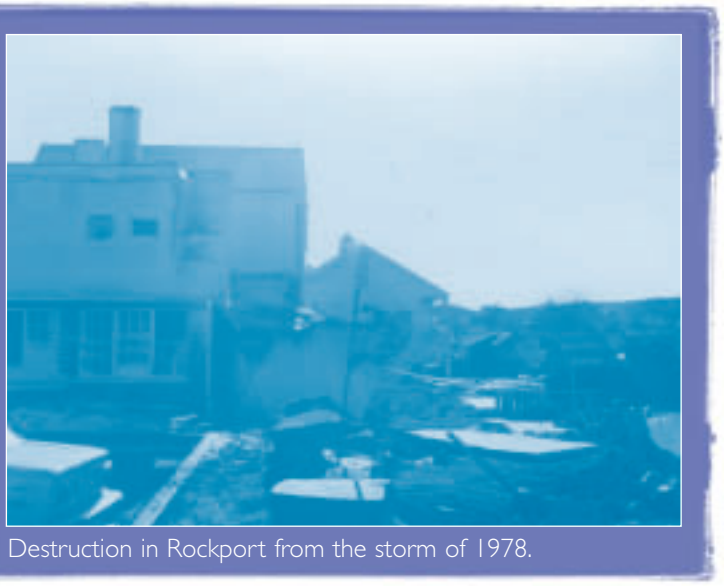
"Effects of a 100-year coastal storm surge in Boston with sea level rise by 2075. This computer graphic shows the floodplain in 2075 with Boston harbor in the foreground and the Charles River in the background."

coastal subsidence and sea level rise will result in a net increase of 0.60 meters (approximately 2 feet) [p. 55]. Higher relative sea level will add to the base elevation of any storm surge, giving it more power to overtop both natural and constructed protection.

A continued trend in the rate of sea level rise could give the typical 10-year storm the intensity of a 100-year storm. Similarly, higher sea levels could make a 100-year storm as powerful as an epic 500-year storm. The potential devastation from these events is easy to imagine and can be quantified.

- By 2050, 1.4 million people in the Boston metro area will live along the coast.

- The total property and contents damages, together with emergency services, from storms coupled with rising sea levels over the next 100 years could reach $94 billion, if no adaptive steps are taken except to rebuild after each flood [p 56].



Joe Pelczarski/Massachusetts Costal Zone Management

Destruction in Rockport from the storm of 1978.

- According to CLIMB's analysis, damage to residential property located in the 100- and 500-year floodplain is expected to average between $7,000 and $18,000 per structure depending on location [p. 57].

How to Adapt

In many cases, some of the expected $94 billion in damages from coastal flooding could be cost-effectively avoided through proactive adaptation strategies. These include limiting development in flood-prone areas, flood-proofing buildings, or installing protective structures.

Thus, while it may be necessary to use expensive structural protection in areas that are highly developed, a less structural approach appears warranted in areas not as densely developed or those considered environmentally sensitive. Our adaptation scenarios were based upon taking action well before 2050. Besides being more cost effective, the less structural Green approach (a) offers no-regrets or co-benefit advantages, (b) is environmentally benign, and (c) allows more flexibility to respond to future unpredictable changes. While uncertainty in the expected rate of sea level rise and damages makes planning difficult, the results also show that no matter what the climate change scenario or the location, not taking action is the worst response.

River Flooding

The Problem

CLIMB developed a method to calculate and compare damage from river flooding related to global warming with flooding likely to occur in the absence of climate change. Accordingly,

flooding related to global warming is expected to impact twice as many properties and double the overall cost of damage during this century.

Total losses throughout metropolitan Boston from river flooding will exceed $57 billion by 2100 assuming no adaptive steps are taken. CLIMB estimated this to be $26 billion more damage than would occur without climate change [p. 81, Table 10.2].

Areas at the fringe of present floodplains have a disproportionately high representation of low value houses that are likely to be uninsured. If, as expected under climate change, these fringe areas are flooded by severe events, households that can least afford to cope with the costs of flooding will become more vulnerable [p. 83, Figure 10.6].

How to Adapt

- Extensive flood-proofing under the Green scenario could reduce river flood damage due to global warming from $26 billion to an estimated $9 billion by 2100 [p. 81, Table 10.2].

- In addition, adopting regulations and incentives that require flood-proofing of all buildings in 100- and 500-year floodplains will further help reduce damage.

- The most costly option would be to take no action at all and simply to repair and rebuild structures damaged by increased flooding from climate change.

PUBLIC HEALTH

The Problem

The CLIMB study examined only health problems related to temperature extremes. Boston normally experiences fewer than 13 days per year when temperatures exceed 90° F, whereas climate change scenarios indicate that by 2030 the region could see 23 or more such days, and by the end of the century there could be 30 days with temperatures over 90° F, more than twice the current number.

The increase in hot days will result in a higher incidence of cardiovascular problems such as heatstroke, heat cramps, heat exhaustion, and heat-related deaths [p. 116]. For example, in August 1975, the day after the temperature reached an all-time high of 102° F, Boston reported 66 deaths per million residents, compared to a mean daily mortality rate of 23.5 per million [p. 121]. Further analysis of morbidity and mortality by the CLIMB study shows that mortality rates rise when temperatures go above 90° F.

How to Adapt

The historical record indicates that over time humans adjust physiologically to temperature extremes. In the future, therefore, rapid drops or sudden rises in temperature may affect only the most vulnerable [p. 117]. Meanwhile, to combat the effects of higher temperatures, adaptive measures will be necessary.

- The most obvious of these are an increase in the use of air conditioning, improvements in health care, and the use of early warning systems for individuals most prone to suffer from excessive heat or cold.

Joe Pelczarski/Massachusetts Costal Zone Management

Coastal damage from the storm in 1978.

- Less evident "Green" strategies include a city-wide program to plant shade trees and the adoption of building codes that require energy-efficient construction materials and designs to reduce heat build-up in dense urban areas. All of these steps will help mitigate the already common "heat-island" effect, which could be exacerbated by climate change [pp. 129-30].

- For these measures to be effective, however, officials must start making aggressive investments now, particularly in improvements to the energy infrastructure to handle the increased summer demand for air conditioning. (See "Energy" below.)

WATER QUALITY

The Problem

The effect of deteriorating water quality due to global warming will primarily harm the environment. Adequate dissolved oxygen (greater than 5 milligrams per liter) is essential for a body of water to support healthy aquatic plants and fish. To determine the effect of climate change on dissolved oxygen, CLIMB studied a typical river, the Assabet, flowing between Westborough and Concord in the western suburbs of metro Boston.

Because of the current low levels of dissolved oxygen, the Massachusetts Department of Environmental Protection (DEP) lists all sections of the Assabet River as unsuitable "for fish, other aquatic life, and wildlife, and for primary and secondary contact recreation" (*i.e.*, swimming, boating, and fishing). Extensive eutrophication is apparent from excessive algae and plant growth attached to the river bottom, particularly behind the five major dams.

Several stretches of the river are already unable to fully support many fish species and plants due to low levels of dissolved oxygen. Even if the population in the Assabet's watershed remained constant and waste water discharges into it were unchanged, increased air temperatures from global warming would lower dissolved oxygen levels by 0.5 milligrams per liter. This represents a significant decrease in dissolved oxygen levels already considered low by federal standards. As oxygen levels continued to decline, many fish species and plants could die. To remedy this, expanded treatment of both direct discharges into the river and polluted run-off would be required at a cost of millions of dollars for the Assabet River alone.

How to Adapt

The additional expense to adapt to climate change is significant because of the high cost of extra nonpoint source pollution management. This underscores the need to consider the integrated impacts of temperature, streamflow, precipitation, land use, population, and water and wastewater management in evaluating the potential impacts of climate change on water quality [p. 142].

ENERGY

The Problem

In the U.S., 58 percent of energy consumption by households and 46 percent of energy use by the commercial sector goes to heating and cooling indoor spaces. More extremely hot days in metropolitan Boston will likely result in an appreciable increase in days of high electricity use for air conditioning. For instance, by 2030 the average number of days in July that require cooling will increase electricity demand by over 24% [p. 36]. This in turn will drive up the need for additional power plants, leading to higher emissions from fossil fuel combustion. In contrast, the number of extremely cold days in winter will decline. While the implications of changing summer and winter energy use may not be significant in overall physical energy terms, there could be significant consequences from the large capital costs to expand the electric energy system for cooling and the contraction of the historical heating oil market [p. 37].

How to Adapt to Increased Energy Use

The Boston region must start planning now to meet future energy demand caused by global warming. Among the "no regrets" options of the Green scenario are construction of thermal shells around buildings to insulate them from extreme temperatures, installation of high efficiency air-conditioners and furnaces to reduce energy demand, and investments in new, less polluting energy resources [p. 154].

Some changes such as energy-efficient building codes for metropolitan Boston and elsewhere will need to be implemented in the near term, or the building stock will become increasingly inadequate for handling the demands of climate change.

CLIMB's analysis of energy use throughout the Boston area reveals several lessons for research, planning, and policy:

- The impact of climate change on heating and cooling energy requirements must be regionalized. Boston residents, for example, are less sensitive to cold temperatures and their "balance point" for heat use is lower than that for, say, Floridians. Similarly, the balance point for air conditioning use in Boston is lower than for other parts of the U.S.

- The analysis of temperature and energy demand should be calibrated to capture daily or even hourly variations in maximum peak requirements during the summer.

- Energy use should be "disaggregated" by energy type and sector (residential and commercial) to accurately reflect the responses of each type to temperature extremes. The commercial sector, for example, is considerably less sensitive to temperature fluctuations than the residential sector.

- A methodological innovation of the CLIMB study is the inclusion of "degree-days" to track annual trend variables. This captures the dynamic fluctuations of energy use rather than relying on an average response for the historical period of analysis. [pp. 51-52]

- By 2030, climate change will be responsible for 25-40% of increased energy demand in the region. If those increases are not taken into account in planning, policy, and investment decisions, then the region may experience shortfalls in energy supply that disrupt the local economy.

TRANSPORTATION

The Problem

More frequent extreme weather events will result in major increases in delays and lost trips during storm periods due to road flooding over the course of the 21st century.

The magnitude of hours and trips lost as the result of extreme rainfall events in the metropolitan Boston area will be much higher under a scenario of climate change: aggregate traffic delays during storm periods due to flooded roads could increase by about 80%, and lost trips over the same period are projected to increase by 82% compared to the delays and cancelled trips that would occur without climate change [p. 97].

How to Adapt

It is unlikely that infrastructure improvements such as realignment of roadways, many of which run through river valleys, can be justified on a cost-benefit basis. Thus, increased delays during large storms resulting from global warming are a nuisance that motorists will have to endure as the frequency of extreme rain events increases. Nonetheless, the CLIMB study found that during this century commercial and private motorists could spend an estimated 80% more hours on the road in stormy periods due to traffic delays caused by road flooding from extreme weather events (100- and 500-year storms). The same analysis projected an 82% increase in lost road trips because of flooding attributable to global warming [p. 97].

WATER SUPPLY

The Problem

According to CLIMB's analysis, water supply in the inner core of metropolitan Boston that is served fully or partially by the Massachusetts Water Resources Authority (MWRA) is the least vulnerable element in the region's infrastructure. This is because of the low demand on this system at present. Under the climate change model predicting lowest streamflows in the region, local water systems relying totally upon local supplies will need to draw on the MWRA regional water authority system to supplement their supplies to maintain acceptable local water service under climate and demographic changes. Yet despite these higher demands on the MWRA under this "Build-Your-Way-Out" option, the reliability of the MWRA regional water system will remain manageable in the future under climate and demographic changes.

How to Adapt

Presently the MWRA is not obligated to serve all locally supplied systems in event of temporary or permanent shortages. This could become necessary, however, by the end of this century. Therefore, local systems should consider anticipating climate and demographic changes by using adaptation actions such as demand management and other measures outside the scope of this study. Suggestions include:

- improving in-stream flows through better storm water management,
- increasing system storage capacity with reservoirs or aquifer use, and

- considering using such water supply sources as reclaimed wastewater and desalination.

Implementation of such actions has historically involved long lead-times [p. 155].

OVERALL CONCLUSIONS

CLIMB's research provides the following major conclusions.

Anticipatory Actions.–A common finding of CLIMB's analyses is that failure to take any adaptation action is the most ineffective and expensive response. The full dynamic analyses showed, and localized case studies implied, that early actions well before 2100 result in less total adaptation and impact costs to the region. Some examples include:

- implementing both structural and nonstructural coastal flood-management strategies before 2050 to reduce the total costs of flood mitigation and impacts
- maintaining policies to improve health care
- enacting regulations to encourage more energy efficient housing stock
- integrating water quality management to include land use, drainage, and waste water treatment, and
- continuing to maintain redundancy in road networks.

Co-Benefits.–Because of the integration of sector impacts and adaptation actions, CLIMB demonstrates that proactive steps in one sector will benefit other sectors, particularly in the case of flood management, and in most cases are beneficial even if climate change is less severe than CLIMB's scenarios assume. For example, land use policies that limit development in flood-prone areas, thus reducing the impacts of flooding and storm damage, also improve water quality and overall environmental quality. Because early action mitigates future impacts, and because improvements to infrastructure systems require long lead times, the CLIMB study recommends against taking action or responding only after major disasters are incurred.

Land Use.–Another common theme is that, as expected, present and future land use greatly affects the magnitude of climate change impacts. This is because the distribution of the population affects the location of infrastructure and hence the impacts of climate change on it. Moreover, land use affects flood magnitudes and losses, water quality, water availability, and local heat island effects. Prohibition of new development–and where possible, flood proofing or retreat of existing development–in flood zones is an example of land use regulation that can both decrease potential damages to property and improve hydrological conditions, thereby decreasing the severity of flooding. In general, the threat of climate change reinforces the importance of good land use planning.

Environmental Impacts.–Since the emphasis of the research was upon impacts on infrastructure, impacts upon the environment were not directly

considered. Potentially significant environmental impacts such as poorer air and water quality and wetland loss could accompany direct impacts on infrastructure. Generally, adaptation measures that lessen an infrastructure impact also reduce environmental impacts. Furthermore, such steps may mitigate greenhouse gas emissions. One clear exception is expansion of air conditioning to manage heat stress mortality.

Socio-Economic Impacts.–CLIMB's impact and adaptation analyses, using a variety of indicators, measured some of the socio-economic impacts of climate change on the region's infrastructure. The incremental damage to properties in river flood and coastal zones under an increased frequency of extreme weather events is the most profound of the measurable economic impacts. The analyses, however, did not capture how impacts and the possible benefits of adaptation might be distributed throughout the region by economic sector or household groups (differing in age structure, ethnic mix, economic prosperity and other factors which may influence an individual's ability to adapt). Although disproportional impacts on various socio-economic groups may clearly exist, CLIMB did not attempt to evaluate them.

Other and Hybrid Adaptation Actions.–In most cases, the CLIMB study standardized and simplified its analyses by examining three adaptation responses. These options, however, were never intended to include all possible adaptation strategies. There are many actions that were not considered, such as offshore protection structures or shoreline retreat, as well as possible combinations of actions by location or hybrid adaptation such as Ride-It-Out in one area and GREEN in another. As shown, however, in the discussion of coastal flooding, and as should be expected, hybrid adaptation strategies are anticipated to be more beneficial than a single type of response.

Adaptive Actors and Institutions.–The adaptation responses considered in this research will require actions by many participants ranging from private citizens to the federal government. Our analysis, as well as related outreach activities, indicates that local levels of government (municipalities and counties) will play an especially critical role in adaptation. Due to the complementarities of effective adaptation actions, a coordinated response strategy will be necessary.

Principal Authors of the CLIMB Report

Dr. Paul Kirshen is Research Professor in the Department of Civil and Environmental Engineering and the Fletcher School of Law and Diplomacy of Tufts University. He holds a Ph.D. in Civil Engineering from M.I.T. and is an expert on water resources. At Tufts, Dr. Kirshen directs the Water: Systems, Science, and Society (WSSS) Interdisciplinary Research and Graduate Education Program and is co-founder and steering committee member of Mystic Watershed Collaborative. He has studied the impacts of climate change and variability in the USA, Asia, and Africa and published reports, papers, and book chapters on these topics.

Dr. William P. Anderson is Professor and Associate Chairman of the Department of Geography at Boston University where he is also a member of the Center for Transportation Studies. His areas of expertise include transportation studies; economic geography; urban geography; energy and environmental studies; urban and regional economic modelling; interregional and international migration; international trade; and quantitative methods. He has conducted research funded by research councils and government agencies in the U.S., Canada, and Mexico as well as by the World Bank. He is the author of over 40 refereed papers and book chapters as well as numerous technical reports. He has edited two forthcoming books and is co-author of *Integration of Transport and Trade Facilitation: Selected Regional Case Studies*, published by the World Bank.

Professor Matthais Ruth holds the Roy F. Weston Chair in Natural Economics and directs the Environmental Policy Program in the School of Public Policy at the University of Maryland, College Park, He is also Co-Director of the Engineering and Public Policy Program and Professor of Environmental Economics and Policy. Professor Ruth is an expert on dynamic modeling of non-renewable and renewable resource use, industrial and infrastructure systems analysis, and environmental economics and policy. He is the author of several books and over one hundred articles and book chapters on various aspects of environmental economics and modeling.

APPENDIX 4
CITY OF SEATTLE
OFFICE OF SUSTAINABILITY AND ENVIRONMENT
CLIMATE PROTECTION WEB SITE

Climate Protection

What is the City of Seattle's role in Climate Protection?

Global warming poses the single largest environmental threat with consequences for economies and communities throughout the world. While continuing to press for national leadership to curb greenhouse gas emissions, the City of Seattle has chosen to take actions now, believing that actions by local governments and its citizens and businesses can make a difference. And, too with some exceptions, strategies that reduce greenhouse gas emissions also lead to cleaner air..

Some may view climate change as a remote global problem that is beyond the capacity – and responsibility – of local governments to solve. But when we consider what makes our region so unique and naturally abundant, we realize that global climate change is in fact a profoundly local issue – both cause and effect. It's here at home, especially in our cities, where we drive the cars and use the power that generates greenhouse pollution. It's our choices as communities and individuals about energy supply and use, transportation, solid waste, and land use that determine the future trajectory of greenhouse gas emissions.

Scientists project that, due to rising temperatures, the Pacific Northwest can expect higher temperatures, wetter winters, drier summers, reduced river flows, increased coastal flooding and erosion and decreased forest health and productivity. Snowpack – the region's natural storage system for water supply and hydroelectricity - is likely to decline by half within our children's lifetimes.

Responding to global climate change has been a City priority since the early 1990s. Since then Seattle has demonstrated day in and day out that local climate solutions are also about responding to our own most pressing local challenges. Challenges like reducing traffic congestion and providing more efficient transportation alternatives; or curbing urban sprawl by increasing affordable housing in the City or stretching the available supply of renewable hydroelectricity through increased energy efficiency. Clearly, some of the best things that respond to climate change are also some of the best things to improve the community.

Most of the hottest years on record have occurred in the past decade, while studies indicate that that decade was the hottest in 1,000 years.

What actions has Seattle taken to tackle global warming?

Many activities are underway in the City. Some highlights include the following:

- In 2000, the City adopted Resolution 30144, committing the City's municipally owned electric utility, Seattle City Light, to an electric energy resource strategy that produces zero net greenhouse gas emissions. Seattle City Light is now well

on its way to implementing the strategy by contracting for programs and projects that mitigate for the CO2 emissions associated with City Light power purchases.

- Seattle's Public Utilities department, with researchers from the University of Washington is conducting an analysis to incorporate climate change information into Seattle's long-range water supply planning. This study will use state-of-the-art modeling to determine potential impacts of climate change on the snowpack and streamflows specifically in Seattle's Tolt and Cedar River watersheds.
- Along with our regional partners, the Puget Sound Clean Air Agency and King County, Seattle hosted the 2002 Cities for Climate Protection Workshop, which brought together more than 250 local government officials and staff from around the country to focus on strategies and direct actions that reduce greenhouse gas emissions.
- In 2002, the Office of Sustainability and Environment completed an inventory of Seattle's greenhouse gas emissions, both corporate and community. Among the major findings:

  - The City has substantially cut GHG emissions attributable to its operations – by 48 percent, comparing 2000 to 1990 - and projections are that the trend will continue.

  - Without the City's recycling and energy conservation programs, the City's emissions in 2000 would have been more than twice as large as they were.

  - Transportation – cars, buses, trucks, planes, ships -- accounts for 56 percent of community emissions compared to 31 percent for the country as a whole (primarily because our region uses less coal or other GHG emitting electric power sources.)

- As a member of the Puget Sound Clean Air Agency's Board of Directors, the City of Seattle was instrumental in adding climate protection as a program priority for the Agency – adding to our list of regional partners that are investing in climate protection strategies.

- Early in 2002, Seattle was one of the first local governments to join Northwest Climate Connections, a new project linking organizations from Washington , Oregon, Idaho, Montana, and British Columbia to demonstrate how protecting the climate helps build a healthier, more sustainable region.

A Few Facts

Sea levels could increase by 10 to 20 inches covering parts of Olympia, Everett, Hoquiam, Aberdeen and Willapa Bay.

US equals four percent of the world's population and produces 22 percent of its greenhouse gas emissions.

APPENDIX 5
SEATTLE DEPARTMENT OF TRANSPORTATION
OFFICIAL RESPONSE

SDOT

Seattle Department of Transportation

Gregory J. Nickels, Mayor

Grace Crunican, Director

MEMORANDUM

TO: Megumi Sumitani
Office of City Auditor

FROM: Grace Crunican, Director
Seattle Dept. of Transportation

DATE: August 2, 2005

SUBJECT: Comments on the Climate Change Audit Report

The Seattle Department of Transportation appreciates the work of the City Auditor's Office staff in looking at how SDOT is adapting its programs, projects and services for the effects of regional climate change. As you know, our Mayor is a leader in the climate change arena. In his Climate Protection Agreement he challenged Seattle and other U.S. cities to meet or beat the goals of the Kyoto protocol, which call for a 7 percent reduction in greenhouse gas emissions. His challenge was met with unanimous support at the U.S. Conference of Mayors meeting earlier this summer. In SDOT we are trying to do our part to mitigate the climate change through our operational programs and capital program. The following comments address the Auditor's recommendations in the five areas that warrant further consideration concerning climate change.

Flooding and Landslides

As noted in the report, Seattle Public Utilities has the primary responsibility for responses to floods and landslides as well as the design integrity of the drainage system. SDOT does respond in emergencies, and is concerned with the structural integrity of bridges or walls with shallow footings that could be endangered. SDOT maintains a regular maintenance and inspection program to monitor the condition of structures that would possibly be endangered by rising flood levels. Given the constraint on resources, and the uncertainty of the full future impacts of climate change, SDOT believes that immediate additional action is not possible or warranted.

Seawall Conditions

As noted in the report, the Alaskan Way Seawall project is taking into consideration a rise in sea level over the design life of the structure.

Seattle Municipal Tower, 700 5th Avenue, Suite 3900, PO Box 34996, Seattle, WA 98124-4996
Tel: (206) 684-ROAD (684-7623), TTY/TDD (206) 684-4009, FAX: (206) 684-5180
Internet address: http://www.seattle.gov/transportation
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GCIU 804-M

Seawalls are extensive and expensive structures. The department does not anticipate that any others in the City will be replaced in the near to mid-term. As with the Alaskan Way Seawall, any future project would look at historical data and consider the sea level information during design. Given the department's constraint on resources, no other action with regard to seawalls is recommended or contemplated at this time.

Bridge Conditions

The Auditor's report identified bridges as an area of concern, primarily as increased maintenance could be experienced for expansion joints, monitoring bridge footings, and the clearance over the water of one of our bridges (the E. Duwamish Waterway bridge). The report notes that the Department monitors its bridges closely, but does not have long term implications of climate change under consideration. Given the very long term and unknown nature of the changes expected from climate change, and the short term planning horizon for biennial operating budgets, it seems that the department is doing what is called for in the short term. In the long term, we will consider the predicted changes in sea levels as we plan for the resources needed to improve existing structures.

Roadway Conditions

The report points out that potential climate change makes it "even more important to perform adequate ongoing maintenance" on streets and roads. The Department agrees that adequate ongoing maintenance is of the utmost importance and notes that current resource constraints are the only obstacle to a more robust maintenance program for streets and roads.

Urban Forestry

Dry, hot summers that may be indicative of climate change also raise the issue of additional maintenance effort necessary to preserve the department's landscaped areas. As indicated, resource constraints are the primary obstacle to a more robust maintenance program. The department is responding currently, insofar as it is practical, by installing drought–resistant vegetation.

In summary, the report points out that climate change may bring about results that the Department would need to cope with in planning new projects, or in the maintenance of our existing infrastructure. The uncertainties and relatively long term nature of this phenomenon still argue for a prudent approach: one that combines watchfulness in following trends in climate change, including anticipating how climate change may increase our resource needs, while we continue with our efforts to mitigate the causes.

The report suggests that the Department undertake a study or studies to consider how regional climate change should or could be included in planning. Until that study (or a citywide study) occurs, our approach is to ensure that climate change issues are included at the scoping phase of all new projects to ensure that they are addressed appropriately.

In terms of mitigating climate change, the department is taking a proactive approach. Through the implementation of our Environmental Management System, we track greenhouse gas emissions, participate in the Fleet Fuel Use initiative, City Commute Trip Reduction Program, and Bike and Pedestrian program to name a few. In addition, our Transportation Strategic Plan focuses on investing in a transportation system that reduces reliance on the automobile and protects our environment. We have reduced our use of CFCs at our maintenance shops and we have reduced our use of solvent based striping paints, and reduced CO2 emissions by the use of asphalt in some cases for paving instead of concrete.

These efforts are a significant way that Seattle Department of Transportation has operationalized our goal to mitigate climate change. We will keep up all of these actions and look forward to further citywide discussions on this priority issue. Thank you for the opportunity to respond to your audit report.

APPENDIX 6
UNIVERSITY OF WASHINGTON CLIMATE IMPACTS GROUP
OFFICIAL REMARKS

CLIMATE IMPACTS GROUP

Climate Science in the Public Interest

Center for Science in the Earth System (CSES)

Joint Institute for the Study of the Atmosphere and Ocean (JISAO)

University of Washington
Box 354235
Seattle, Washington
98195-4235

206.616.5350
FAX 206.616.5775

www.cses.washington.edu/cig

Climate Impacts Group
UNIVERSITY OF WASHINGTON

100% POST-CONSUMER RECYCLED PAPER
PRINTED WITH SOY-BASED INKS

Date: July 29, 2005

To: Susan Cohen, Seattle City Auditor
Seattle Municipal Tower
700 Fifth Avenue, Suite 2410
Seattle, WA 98104-5030

From: Edward L. Miles, Director
Climate Impacts Group
University of Washington

Re: Report on Climate Change Audit for the Seattle Department of Transportation

Dear Ms. Cohen:

We at the University of Washington's Climate Impacts Group are thrilled that Seattle has begun exploring the implications of climate change for the operations of the Seattle Department of Transportation (SDOT).

As you know, current climate change projections call for increases in Pacific Northwest temperatures of approximately 2.7 deg F by the 2020s and 4.1 deg F by the 2040s, net sea level rise at Seattle of 1.5-4 feet by 2100, and increased winter precipitation (all compared to the 1990s). The implications of these changes for the PNW include decreased winter snowpack and summer streamflow, increased winter streamflow and risk of flooding, negative impacts on salmon throughout the freshwater phase of their lifecycle, increased stress for currently drought-stressed trees, and increased coastal flooding, erosion, and landslides.

Because the projected climate changes for the next few decades are essentially independent of our future choices concerning greenhouse gas emissions, it is important that managers begin to prepare for these changes.

- **Recognize that the past is no longer a reliable guide to the future.** It is important to adjust planning that has been tied to past climate conditions to also account for projected future change, as SDOT has begun to do in the Alaska Way Seawall Wave Study.

- **Translate regional impacts of climate change into implications for management.** With managers and planners at SDOT, the Seattle City Auditor has taken the important first step of examining how projected

impacts of climate change align with management mandates and objectives.

- **Monitor climate conditions and watch for projected impacts** to stay apprised of change as it occurs.

- **Plan for future change**. Although some significant changes may still be 20-40 years away, they are within the design life of structures currently being maintained, repaired, and rebuilt.

We applaud the City Auditor and SDOT for taking the important first step of examining how projected impacts of climate change align with SDOT mandates and objectives and commend SDOT for beginning to address future climate change in their Alaska Way Seawall study and in plantings managed by their urban forestry division. SDOT's current and future consideration of climate change will be a good companion to efforts by other City departments to examine their potential vulnerability to future climate conditions (such as Seattle Public Utilities' examination of climate change impacts on the City's water supply). We strongly support both the expansion of these efforts to other City departments and the proposed coordinated development of consistent climate change scenarios for use within and beyond the City.

The Climate Impacts Group is available for further information and assistance. We will continue to develop up-to-date climate change information for the Pacific Northwest region and to post these research results on our web-site: www.cses.washington.edu/cig. Please contact us if we can be of any assistance in the future.

Office of City Auditor's Report Evaluation Form

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HELP US SERVE THE CITY BETTER

Our mission at the Office of City Auditor is to help assist the City in achieving honest, efficient management and full accountability throughout the City government. We service the public interest by providing the Mayor, the City Council and City managers with accurate information, unbiased analysis, and objective recommendations on how best to use public resources in support of the well-being of the citizens of Seattle.

Your feedback helps us do a better job. If you could please take a few minutes to fill out the following information for us, it will help us assess and improve our work.

* *

Report: *Climate Change Will Impact the Seattle Department of Transportation*

Release Date: August 9, 2005
Please rate the following elements of this report by checking the appropriate box:

	Too Little	Just Right	Too Much
Background Information			
Details			
Length of Report			
Clarity of Writing			
Potential Impact			

Suggestions for our report format: _____

_____

_____

Suggestions for future studies: _____

_____

Other comments, thoughts, ideas: _____

_____

_____

Name (Optional):

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Thanks for taking the time to help us.

Fax: 206/684-0900
E-Mail: auditor@seattle.gov
Mail: Office of City Auditor, PO Box 94729-4729, Seattle, WA 98124-4729
Call: Susan Cohen, City Auditor, 206-233-3801
www.cityofseattle.net/audit/